FINAL REPORT

UV-B RADIATION EFFECTS ON PHOTOSYNTHESIS AND PLANT GROWTH

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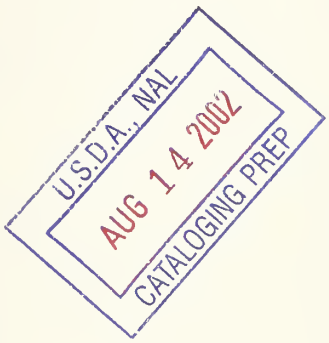

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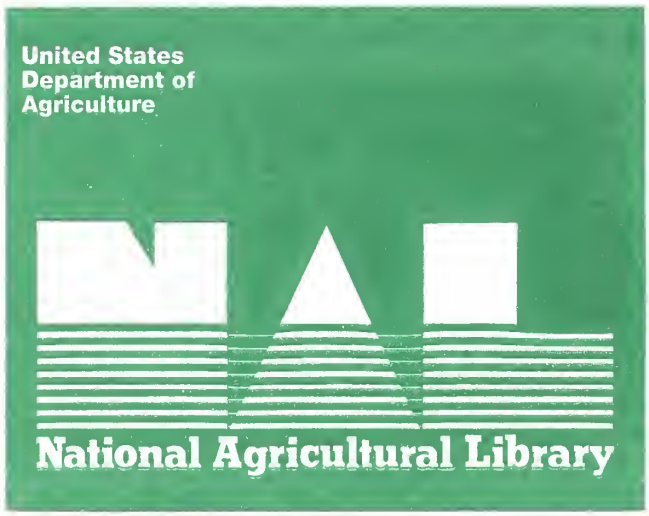
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Introduction

A reduction of the atmospheric ozone layer through interactions with oxides of nitrogen or halomethanes would result in increased levels of terrestrial UV-B (280-320 mm) radiation (Green, Sawada and Shettle, 1974). An increase in the UV-B radiation component of the global irradiance could result in significant biological effects since UV-B radiation is readily absorbed by nucleic acid and protein chromophores (Giese, 1964).

The present study was initiated to evaluate plant responses to UV-B radiation as would occur under reduced atmospheric ozone concentrations.

Methods and Materials

All studies were completed in a fiberglass greenhouse. Four Westinghouse FS-40 'sunlamps' were maintained approximately 1 M above the plant surface. Each 'sunlamp' was filtered by either 5, 7.5 or 10 mil cellulose acetate. The cellulose acetate filtered lamps were adjusted to produce a gradient of UV-B radiation at the plant surface area. UV-B radiation measurements were made daily with an IRL model 25 Radiometer (Optronics Lab., Silver Springs, Maryland). Spectral irradiance measurements were made prior to treatment initiation and at least weekly thereafter with an Optronics Laboratory model 721 Spectroradiometer. The control treatment for all experiments consisted of four FS-40 'sunlamps' filtered with 10 mil Mylar plastic film adjusted to the same configuration as the corresponding UV-B radiation treatment. The cellulose acetate filters were replaced every third day and the mylar filteres were replaced every other week.

Net photosynthesis of single leaves was determined with a refrigerated open gas circulation system with a model 365 Beckman IR gas analyzer. Air and leaf temperatures within the curvette were measured with five-wire (copper-constantan) thermocouples. A Cambridge model 880 dew-point hygrometer measured changes in water-vapor concentrations. A constant temperature of 27°C was maintained in the curvette during all photosynthetic determinations. Total PAR quanta were monitored in the curvette by a Lambda model LI-190SR quantum sensor. One, 1500-W Westinghouse tunsten-halogen lamp provided an irradiance level of 800 $\mu e \cdot m^{-2} \cdot s^{-1}$ for all photosynthetic determinations. Leaf areas were measured with a Lambda model LI-3000 portable area meter. Photosynthetic rates are expressed on a leaf area (one side) basis.

Indivudal shoots of alkali sacaton (Sporobolus airoides) were transplanted from the field into 10 cm pots. Upon initiation of the UV radiation treatment, all plants were defoliated to a one-inch height above the soil's surface. Thus, leaf growth as measured in this study is regrowth. All other plant material was grown from seed in 10 cm pots in a "Jiffy-7 Plus" medium. The methods for acidic methanol-water extracts from Capsicum frutescens follows the procedures outlined by Caldwell (1968). Absorbance of the extract was measured with a Beckman Model DU spectrophotometer.

Quantification of the UV-B radiation dose was determined with the equation:

$$UV\text{-}B_I = \left[.25\ (\lambda/228.178)^9\right] 4_e \left[4 - (\lambda/228.178)^9\right] \quad (1)$$

Spectral irradiance of all UV-B radiation treatments employed in this

study are presented in Figures 1 and 2.

Results

Leaf growth of alkali sacaton exposed to four UV-B radiation treatments is shown in Figure 3. Each value represents the mean of 21 to 75 measurements. As shown in Figure 3, leaf growth was repressed as a function of the level of UV radiation. Table 1 presents the numerical values and a statistical analysis of the data represented in Figure 3. The control treatment leaf length values were consistently different ($P < .05$) from the UV radiation treated plants only at, and above a level of 7.5 mW . m^{-2} $UV\text{-}B_I$. The 13.9 mW . m^{-2} $UV\text{-}B_I$ treatment resulted in repressed leaf lengths statistically different ($P < .05$) from the other four treatments.

Chile (Capsicum frutescens) responded to UV-B radiation in a manner similar to alkali sacaton through 22 days treatment (see Figure 4). That is, total plant leaf area was repressed as a function of $UV\text{-}B_I$. The values represent the means of four or five plants and all treatment means differed statistically ($P < .05$) except those plants exposed to 4.8 and 5.9 mW . m^{-2} $UV\text{-}B_I$. Similarly, after 55 days treatment, total leaf area, and wet and dry weight of chile, differed between the control and five of the seven UV-B radiation treatments (see Table 2). Variability of plants within treatments C and E probably resulted in the lack of statistical differences between these treatments and the control treatment. However, contrary to the 22 day experiment (see Figure 4), there were no differences between the UV-B radiation treated plants for those parameters evaluated. Since

Figure 1. Spectral irradiance of four Westinghouse FS-40 'sunlamps' each filtered by 5 mil cellulose acetate yielding (A) 4.0, (B) 5.0, (C) 6.8, (D) 9.1 and (E) 10.6 mW . m^{-2} $UV\text{-}B_I$ by equation 1. Measurements were made in a fiberglass greenhouse with a model 721 Optronics Laboratory Spectroradiometer.

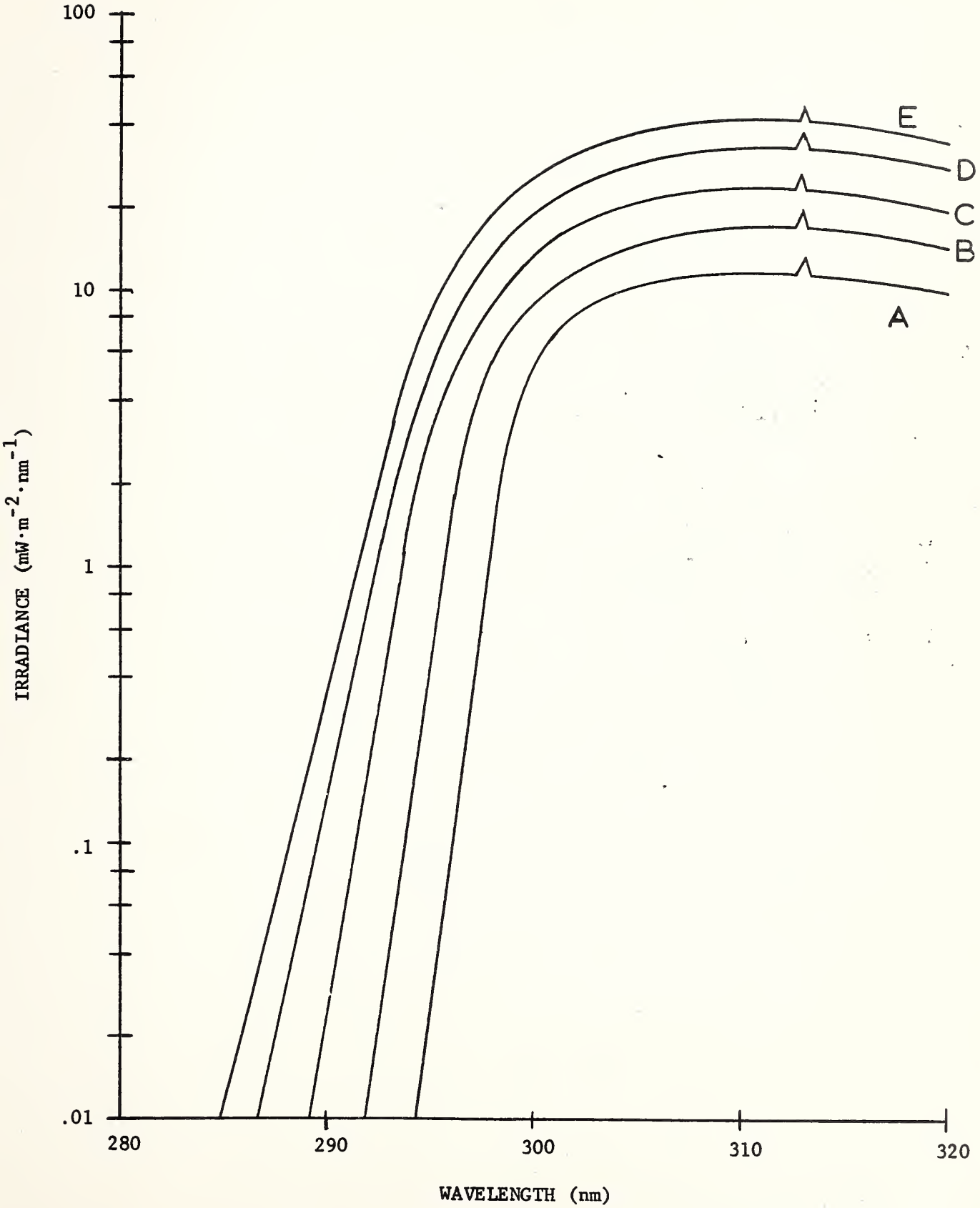

100
10
1
.1
.01
IRRADIANCE (mW·m⁻²·nm⁻¹)
E
D
C
B
A
280
290
300
310
320
WAVELENGTH (nm)

Figure 2. Spectral irradiance of four Westinghouse FS-40 'sunlamps' each filtered by 5 mil cellulose acetate yielding (A) 5.9, (B) 7.7, (C) 9.8 and (D) 14.6 mW . m^{-2} $UV\text{-}B_I$ according to equation 1. Measurements were made in a fiberglass greenhouse with a model 721 Optronics Laboratory Spectroradiometer.

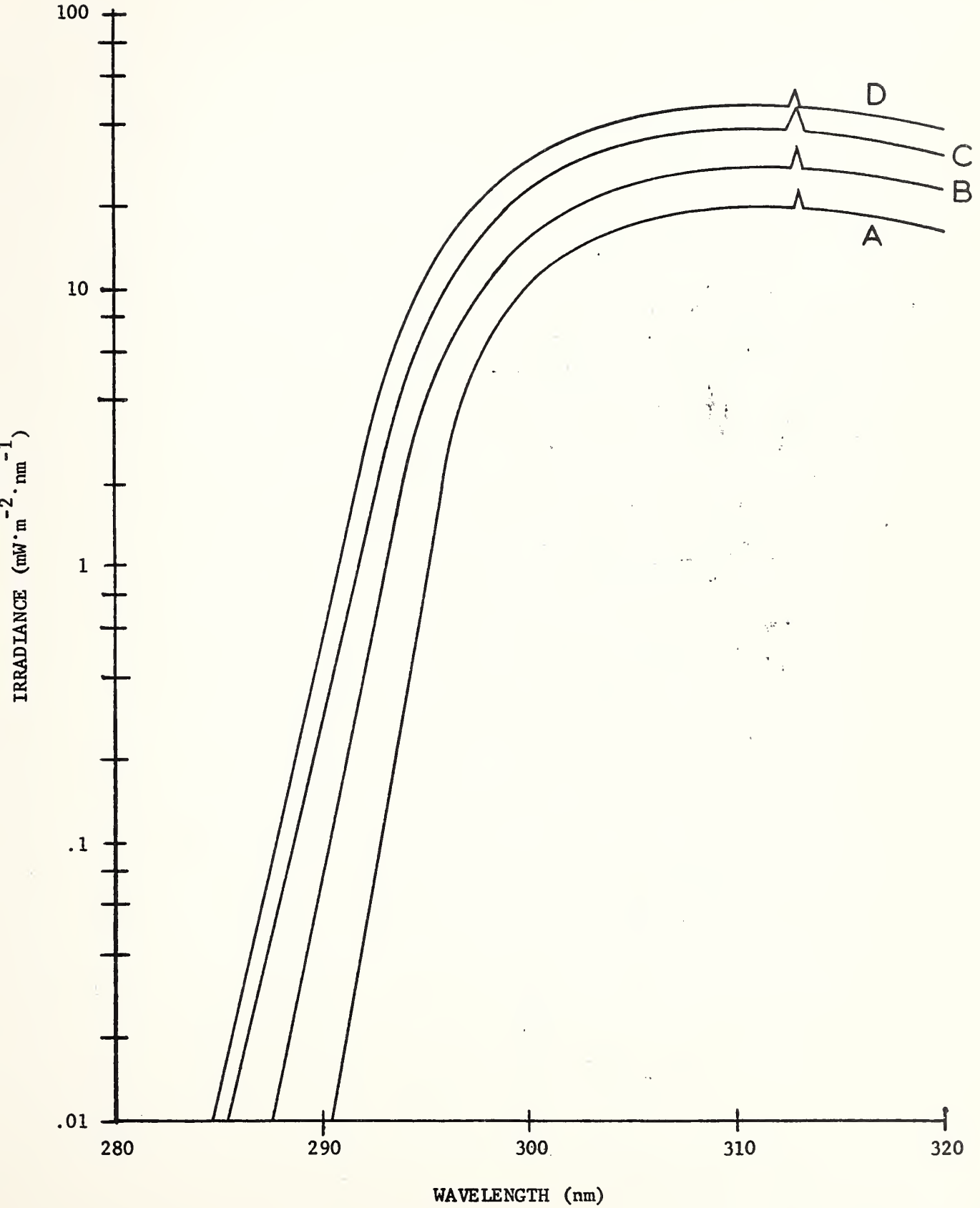

100
10
1
.1
.01
IRRADIANCE (mW·m^{-2}·nm^{-1})
280
290
300
310
320
WAVELENGTH (nm)
A
B
C
D

Figure 3. Leaf length (mm) of alkali sacaton (Sporobolus airoides) exposed to four UV radiation (5.9 (●), 7.5 (▲), 11.3 (X) and 13.9 (Δ) mW . m^{-2} $UV\text{-}B_I$) and a control treatment (O). Each value represents the mean of 21 to 75 individual leaves.

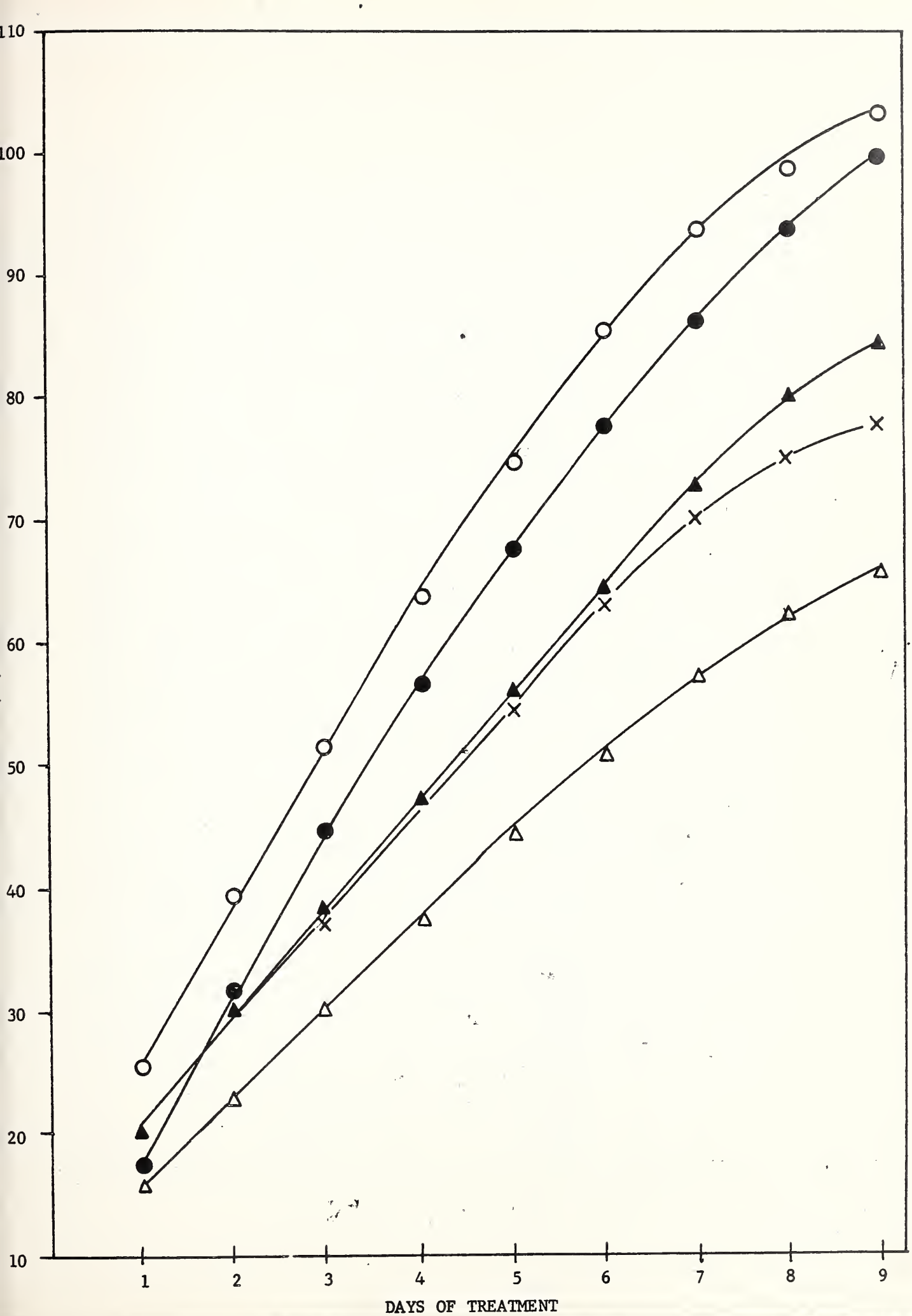

110
100
90
80
70
60
50
40
30
20
10
1
2
3
4
5
6
7
8
9
DAYS OF TREATMENT

Table 1. Leaf growth of ALKALI sacaton (Sporobolus airoides Torr.) exposed to four levels of UV-B radiation (5.9, 7.5, 11.3 and 13.9 mW . m^{-2} $UV\text{-}B_I$) and a control treatment. Each value represents the mean of 21 to 75 measurements.

	$UV\text{-}B_I$ ($mW \cdot m^{-2}$)	Days								
		1	2	3	4	5	6	7	8	9
Control Treatment		2.55^{a}	3.91^{a}	5.15^{a}	6.36^{a}	7.48^{a}	8.53^{a}	9.36^{a}	9.88^{a}	10.32^{a}
UV Treatments										
A	5.9	1.76^{b}	3.14^{b}	4.48^{ab}	5.68^{ab}	6.78^{ab}	7.74^{ab}	8.62^{ab}	9.38^{ab}	9.95^{ab}
B	7.5	2^{ab}	3.07^{b}	3.84^{b}	4.73^{b}	5.62^{b}	6.48^{b}	7.27^{b}	8.00^{b}	8.46^{ab}
C	11.3	1.89^{b}	2.92^{b}	3.82^{b}	4.74^{b}	5.43^{b}	6.43^{b}	7.02^{b}	7.53^{b}	7.78^{b}
D	13.9	1.62^{b}	2.30^{c}	3.01^{c}	3.74^{c}	4.42^{c}	5.09^{c}	5.92^{c}	6.21^{c}	6.58^{c}

Values within the same column followed by different letters differ statistically ($P < .05$).

Figure 4. Total plant leaf area of chile (Capsicum frutenscens) after 22 days exposure to 5 UV radiation treatments (3.3, 4.8, 5.9 and 10.6 mW . m^{-2} $UV\text{-}B_I$). Each value represents the mean of four or five plants.

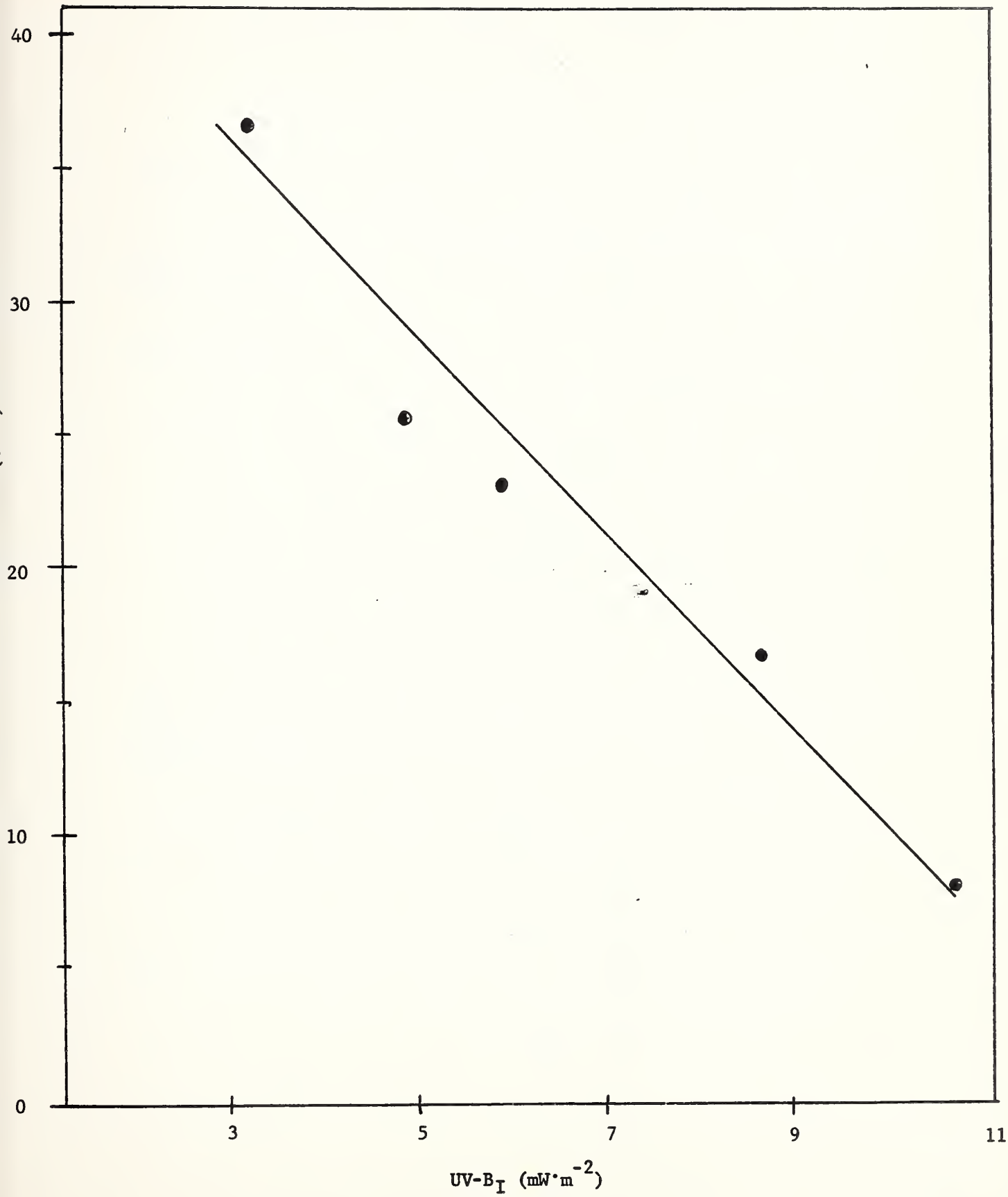

40
30
20
10
0
3
5
7
9
11
UV-B$_I$ (mW·m^{-2})

Table 2. Total leaf area (cm^2), and wet and dry weight of chile (Capsicum frutescens) exposed to 7 UV-B radiation doses (3.3, 5.1, 6.8, 7.7, 9.1, 10.0 and 10.6 $mW \cdot m^{-2}$ $UV\text{-}B_I$) and a control treatment. Each value represents the mean of three to six replicates. A daily exposure period of 7 hours was used for the 55 days of treatment.

	$UV\text{-}B_I$ ($mW \cdot m^{-2}$)	Wet Weight (g)	Dry Weight (g)	Total Leaf Surface Area
Control Treatment		44.6	5.1	753.4
UV-B Treatments				
A	3.3	32.7*	3.4*	582.6*
B	5.1	30.8*	3.3*	564.7*
C	6.8	35.7	3.9	765.3
D	7.7	28.2*	3.0*	528.8*
E	9.1	33.9	3.4	507.2
F	10.0	27.3*	2.9*	500.8*
G	10.6	33.1*	3.4*	613.6*

Values followed by asterisk (*) differ significantly ($P < .05$) from the control treatment.

it was only possible to irradite the topmost leaves of individual plants, a shading effect may have been partially responsible for these results. An alternative or additional factor responsible could be the absorption of UV-B radiation prior to absorption by sensitive chromophores within the leaves. Figures 5 through 12 represent the absorbance of methanol-water-HCL extracts from the topmost leaves of the control and UV-B radiation treated plants. All values represent relative absorbance since they were normalized to Figure 12. Absorbance by this methanol-water-HCL extract contains the flavonoids, some xanthophylls, cuticular waxes and other lipids which represent efficient UV radiation absorbing compounds in plants (Caldwell, 1968; Block, Durrum and Zweig, 1958; Geissman, 1955).

There were no apparent differences between the absorbance of the control treatment (Figure 5) extracts and those from plants exposed to 3.3 (Figure 6) and 6.8 (Figure 8) mW . m^{-2} $UV\text{-}B_I$. However, all other levels of $UV\text{-}B_I$ resulted in increased absorbance within the UV-B radiation waveband. In addition, absorbance tended to increase with increased levels of $UV\text{-}B_I$. These results tend to suggest that UV radiation absorbing compounds are being produced somewhat according to the intensity of UV-B radiation impinging on the exposed leaves. This increase in UV radiation absorbing compounds would attenuate at least part of the UV-B radiation and, in part, provide a protective screen to the more sensitive cell components.

A dose-response curve for photosynthesis of Cucurbita pepo f.s. early summer crookneck exposed to four levels of UV-B radiation (5.1, 6.8, 7.7 and 9.1 mW . m^{-2} $UV\text{-}B_I$) is presented in Figure 13. The treatments were initiated when the plants were 23 days old from the time of seed germination and all photosynthetic measurements were made on the first leaf after

Figure 5. Relative absorbance of a methanol-water-HCL extract from the topmost leaves of chile (Capsicum frutenscens) in a control treatment.

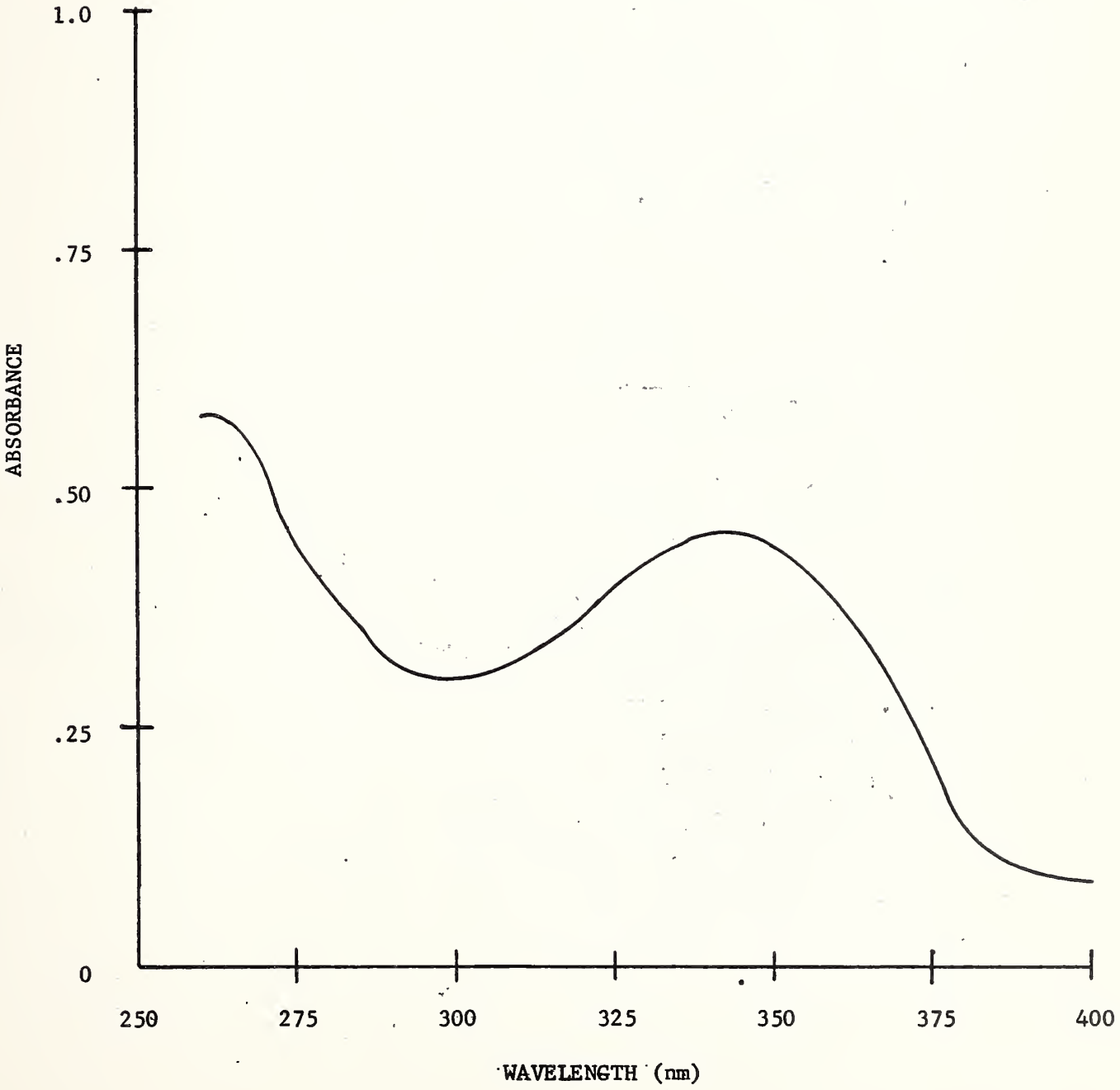

1.0
.75
.50
.25
0
ABSORBANCE
250
275
300
325
350
375
400
WAVELENGTH (nm)

Figure 6. Relative absorbance of a methanol-water-HCL extract from the topmost leaves of chile (Capsicum frutescens) exposed to 3.3 mW . m^{-2} $UV\text{-}B_I$ for 7 hours daily for 55 days.

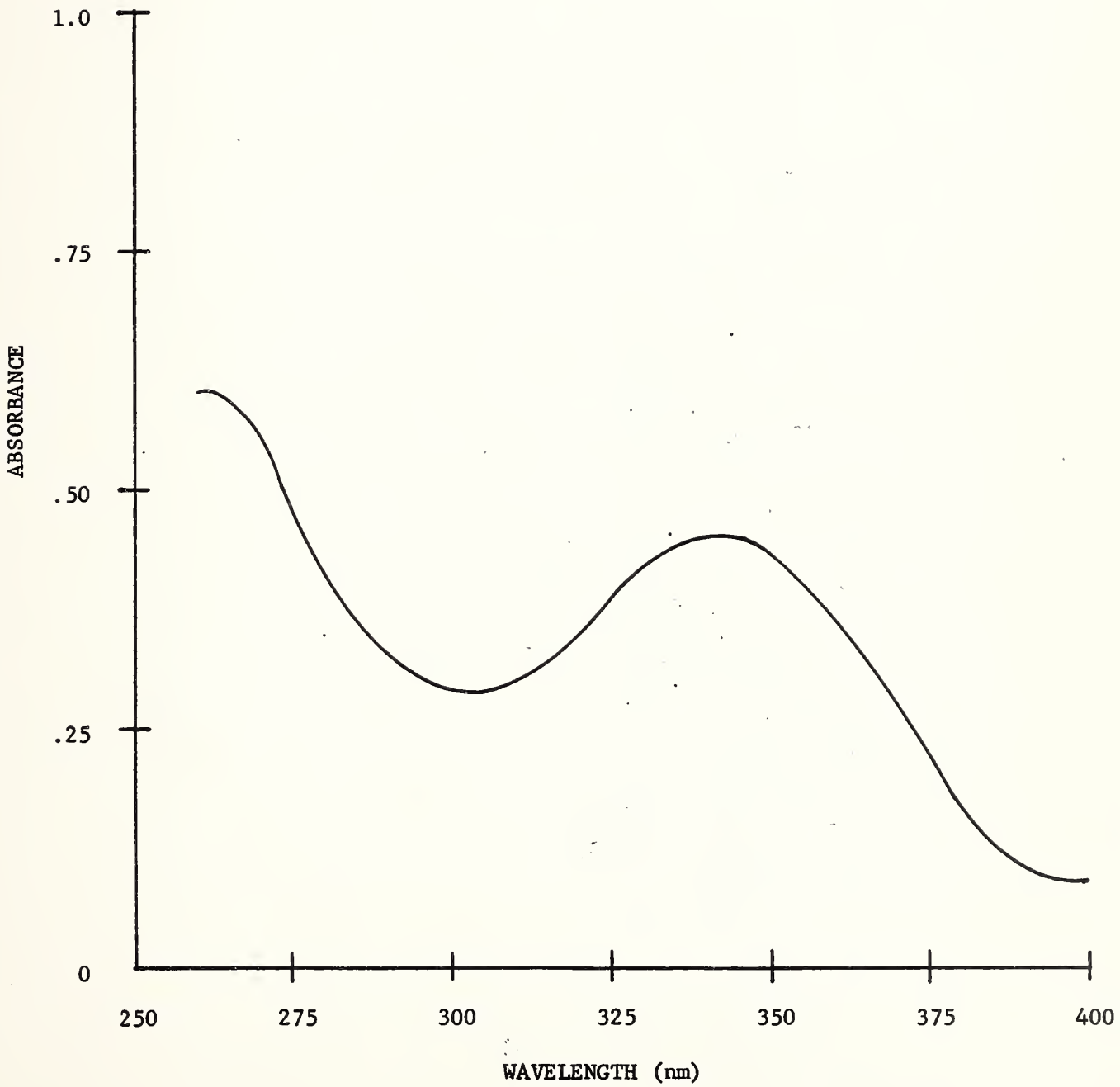

1.0
.75
.50
.25
0
ABSORBANCE
250
275
300
325
350
375
400
WAVELENGTH (nm)

Figure 7. Relative absorbance of a methanol-water-HCL extract from the topmost leaves of chile (Capsicum frutescens) exposed to 5.1 $mW \cdot m^{-2}$ $UV\text{-}B_I$ for 7 hours daily over 55 days

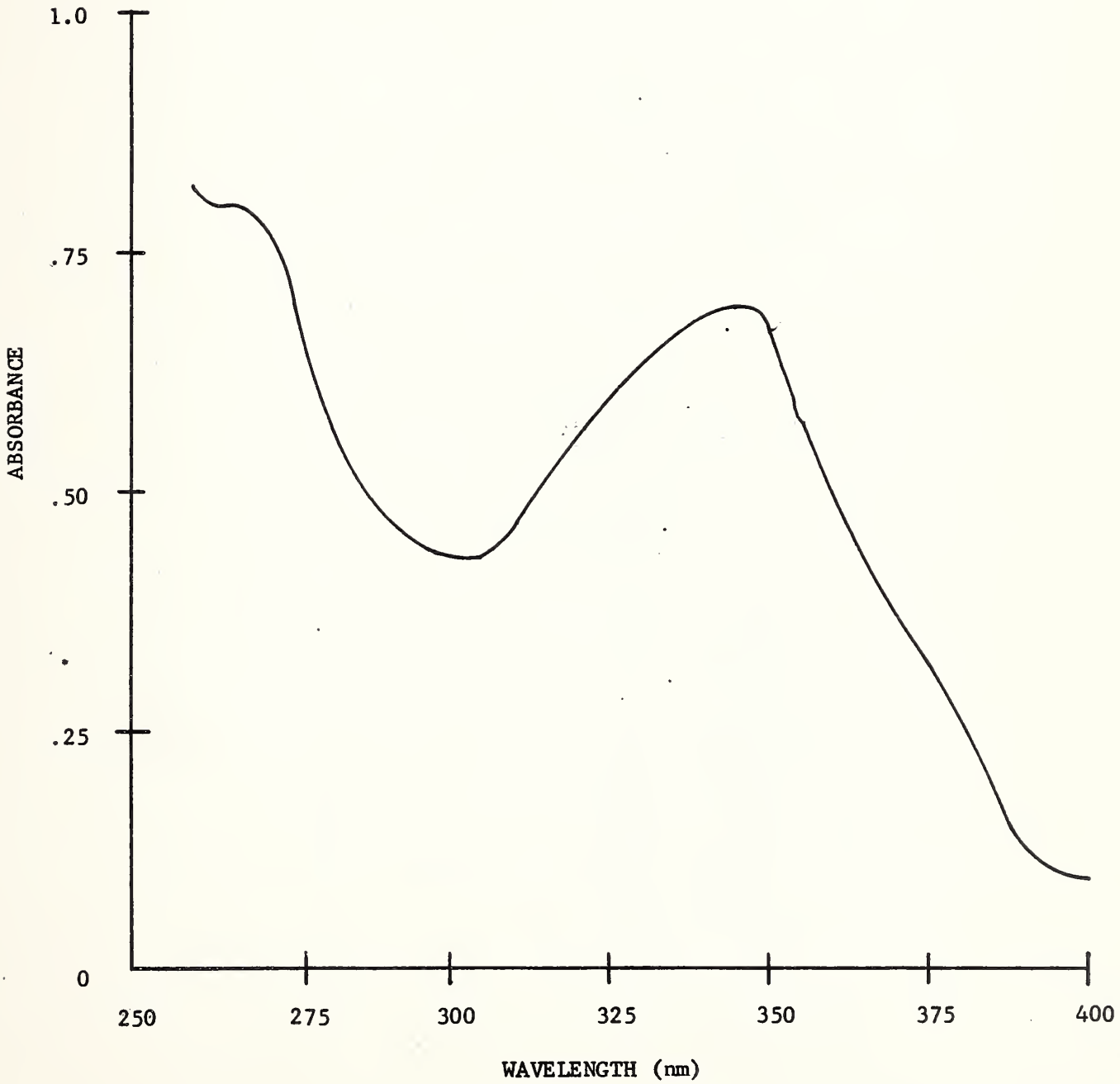

1.0
.75
.50
.25
0
ABSORBANCE
250
275
300
325
350
375
400
WAVELENGTH (nm)

Figure 8. Relative absorbance of a methanol-water-HCL extract from the topmost leaves of chile (Capsicum frutescens) exposed to 6.8 mW . m^{-2} $UV\text{-}B_I$ for 7 hours daily for 55 days.

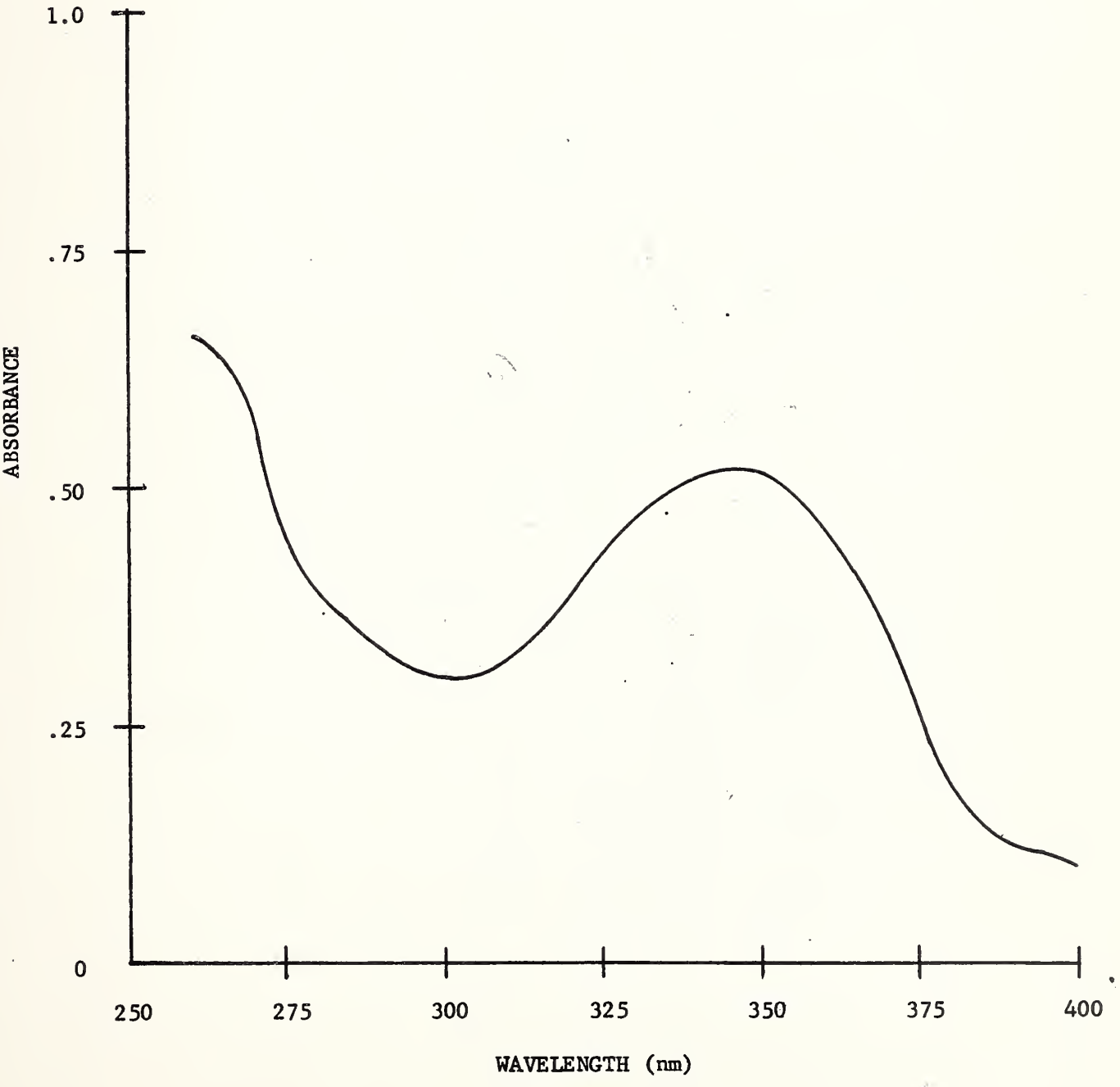

1.0
.75
.50
.25
0
ABSORBANCE
250
275
300
325
350
375
400
WAVELENGTH (nm)

Figure 9. Relative absorbance of a methanol-water-HCL extract from the topmost leaves of chile (Capsicum frutescens) exposed to 7.7 mW . m^{-2} $UV\text{-}B_I$ for 7 hours daily over 55 days.

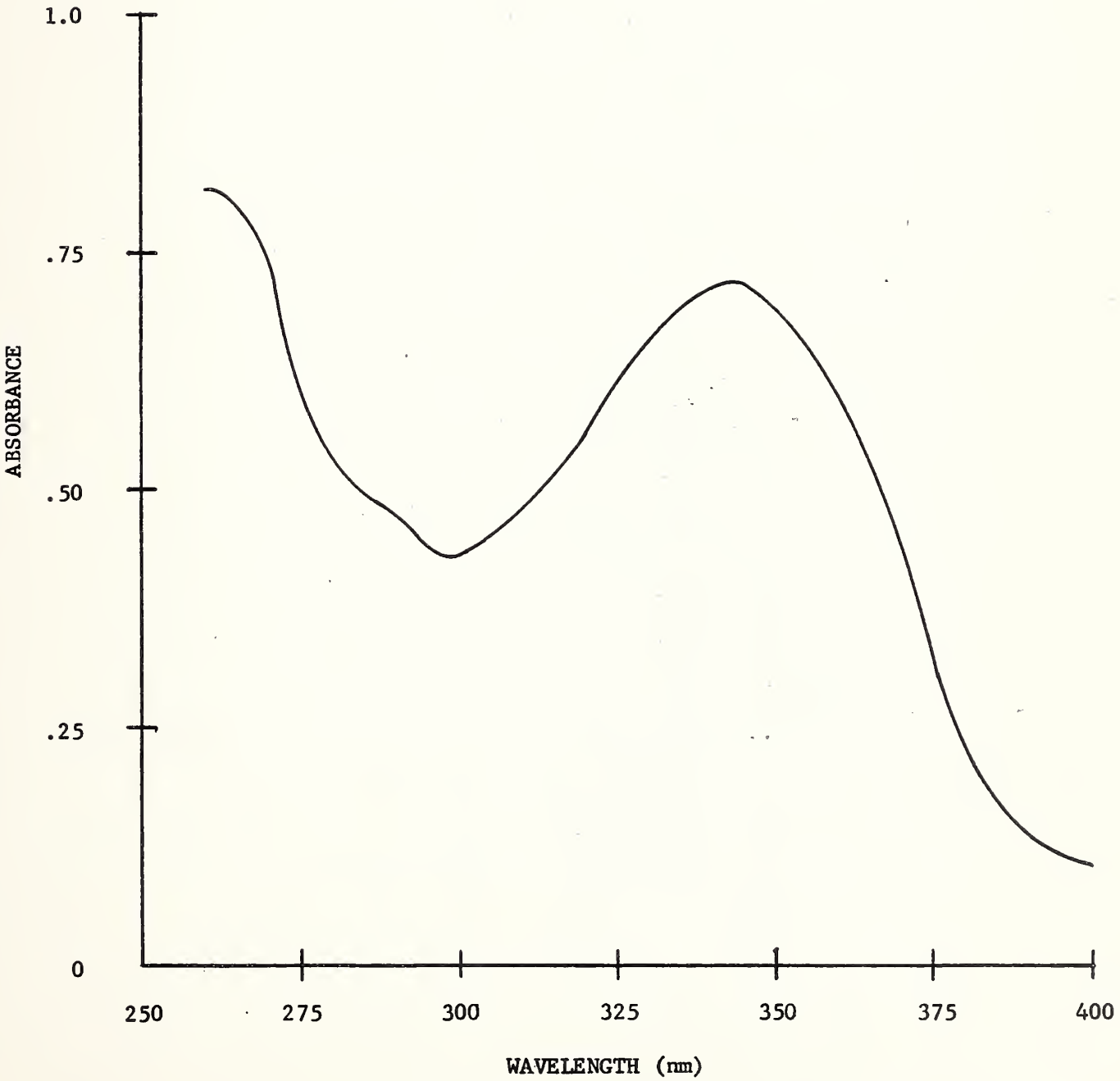

1.0
.75
.50
.25
0
ABSORBANCE
250
275
300
325
350
375
400
WAVELENGTH (nm)

Figure 10. Relative absorbance of a methanol-water-HCL extract from the topmost leaves of chile (Capsicum frutescens) exposed to 9.1 $mW \cdot m^{-2}$ $UV\text{-}B_I$ for 7 hours daily over 55 days.

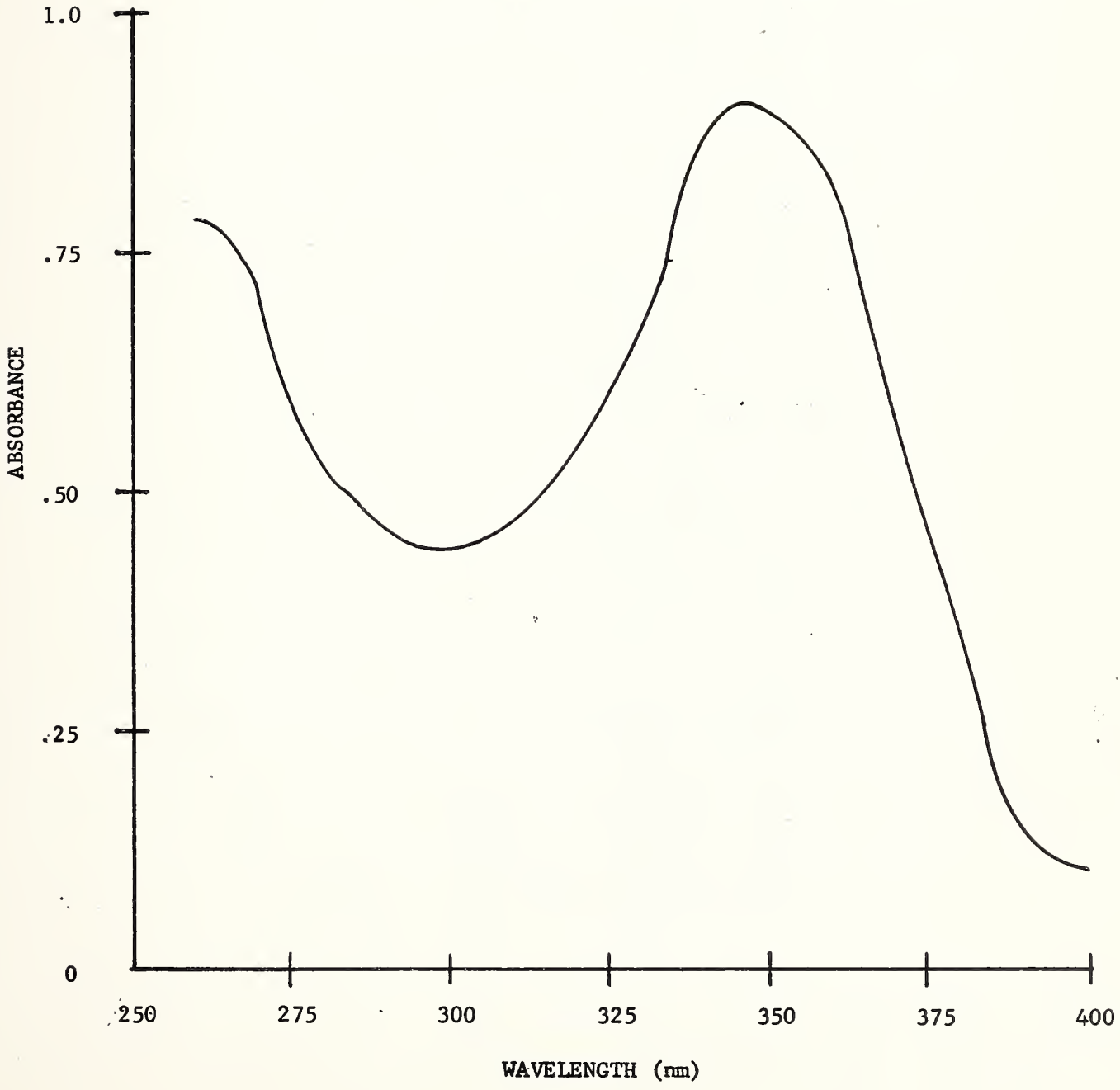

1.0
.75
.50
.25
0
ABSORBANCE
250
275
300
325
350
375
400
WAVELENGTH (nm)

Figure 11. Relative absorbance of a methanol-water-HCL extract from the topmost leaves of chile (Capsicum frutescens) exposed to 10.0 mW . m^{-2} UV-B_I for 7 hours daily over 55 days.

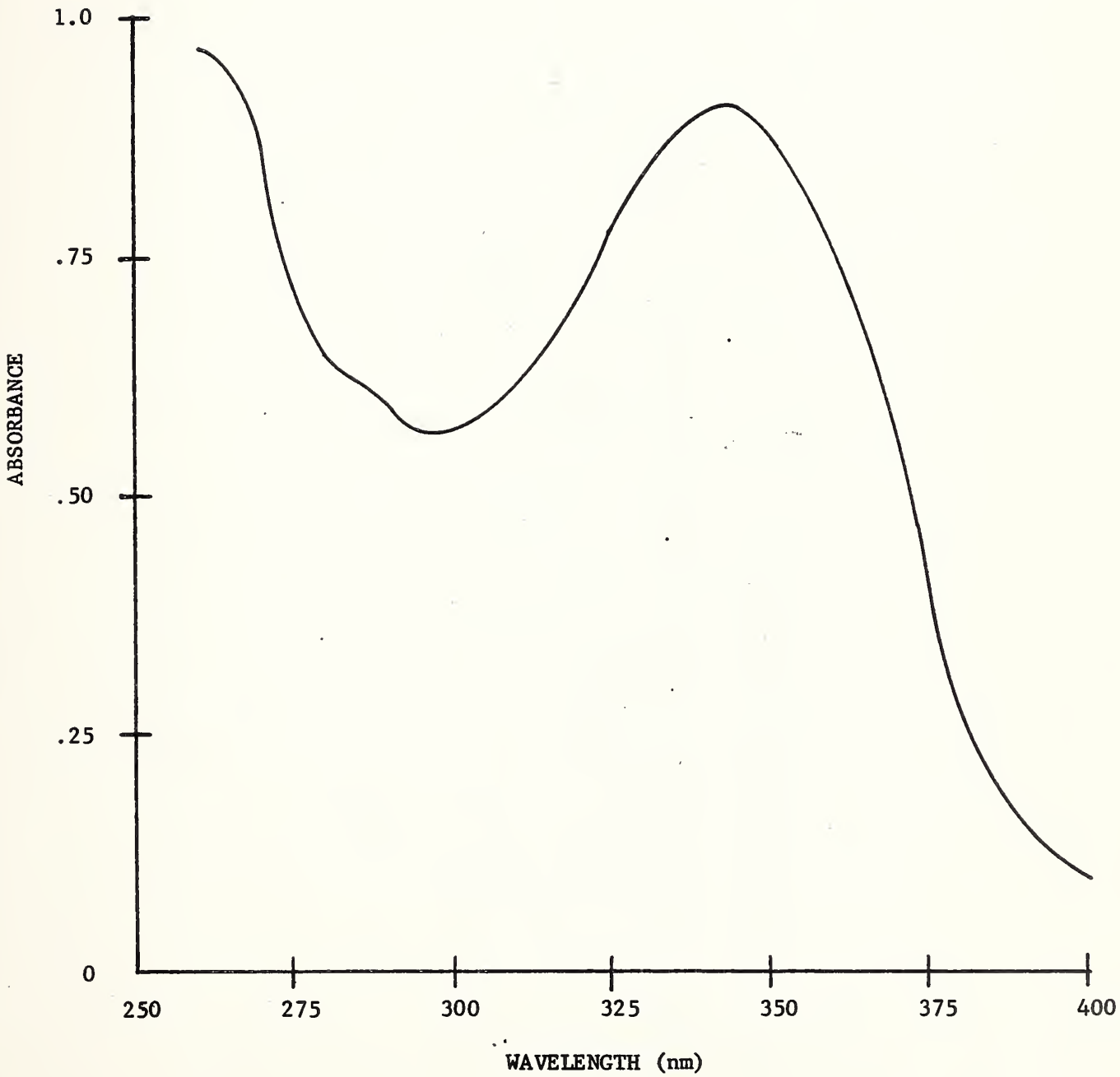

1.0
.75
.50
.25
0
ABSORBANCE
250
275
300
325
350
375
400
WAVELENGTH (nm)

Figure 12. Realtive absorbance of a methanol-water-HCL extract from the topmost leaves of chile (Capsicum frutescens) exposed to 10.6 $mW \cdot m^{-2}$ $UV\text{-}B_I$ for 7 hours daily over 55 days.

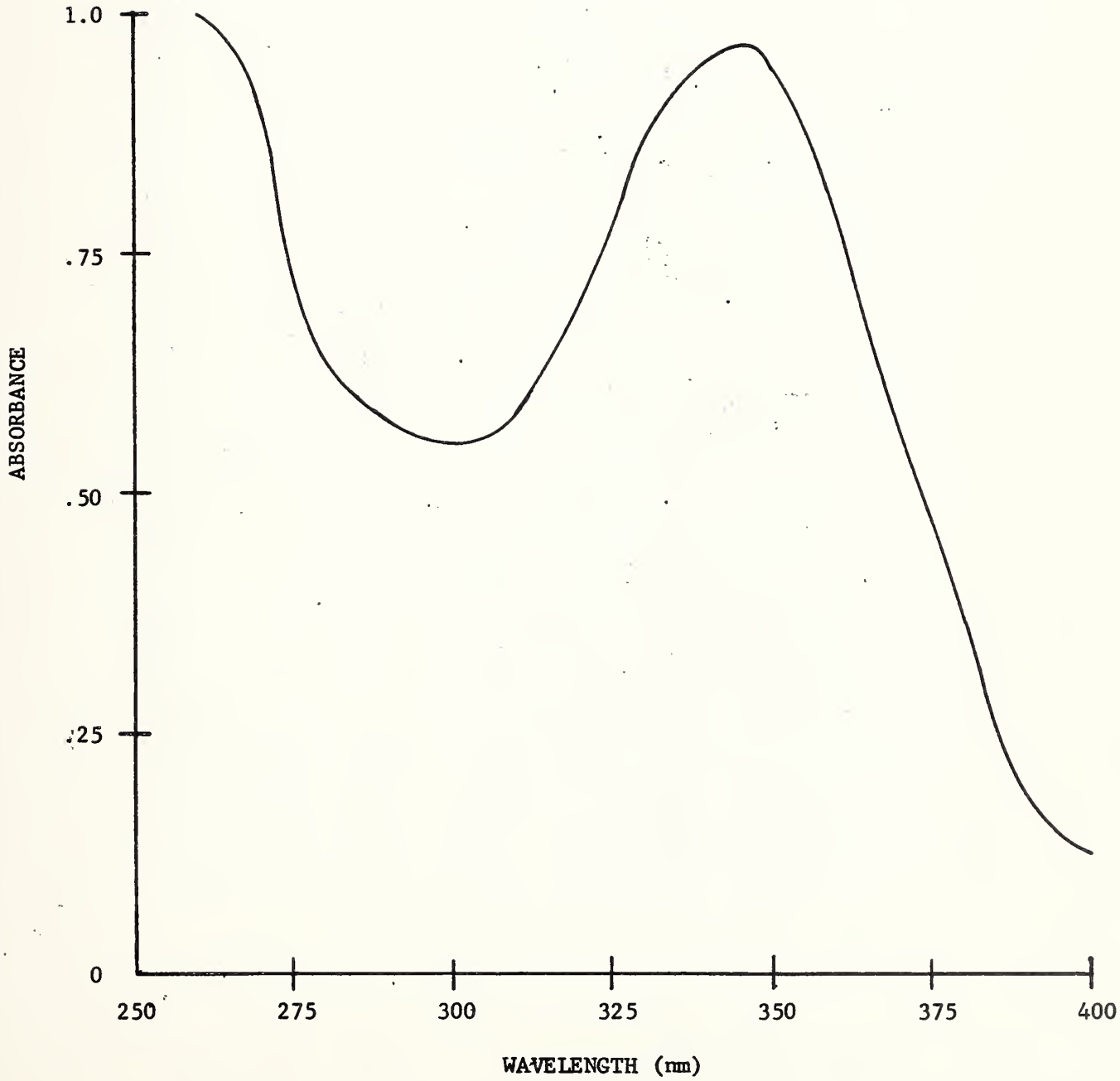
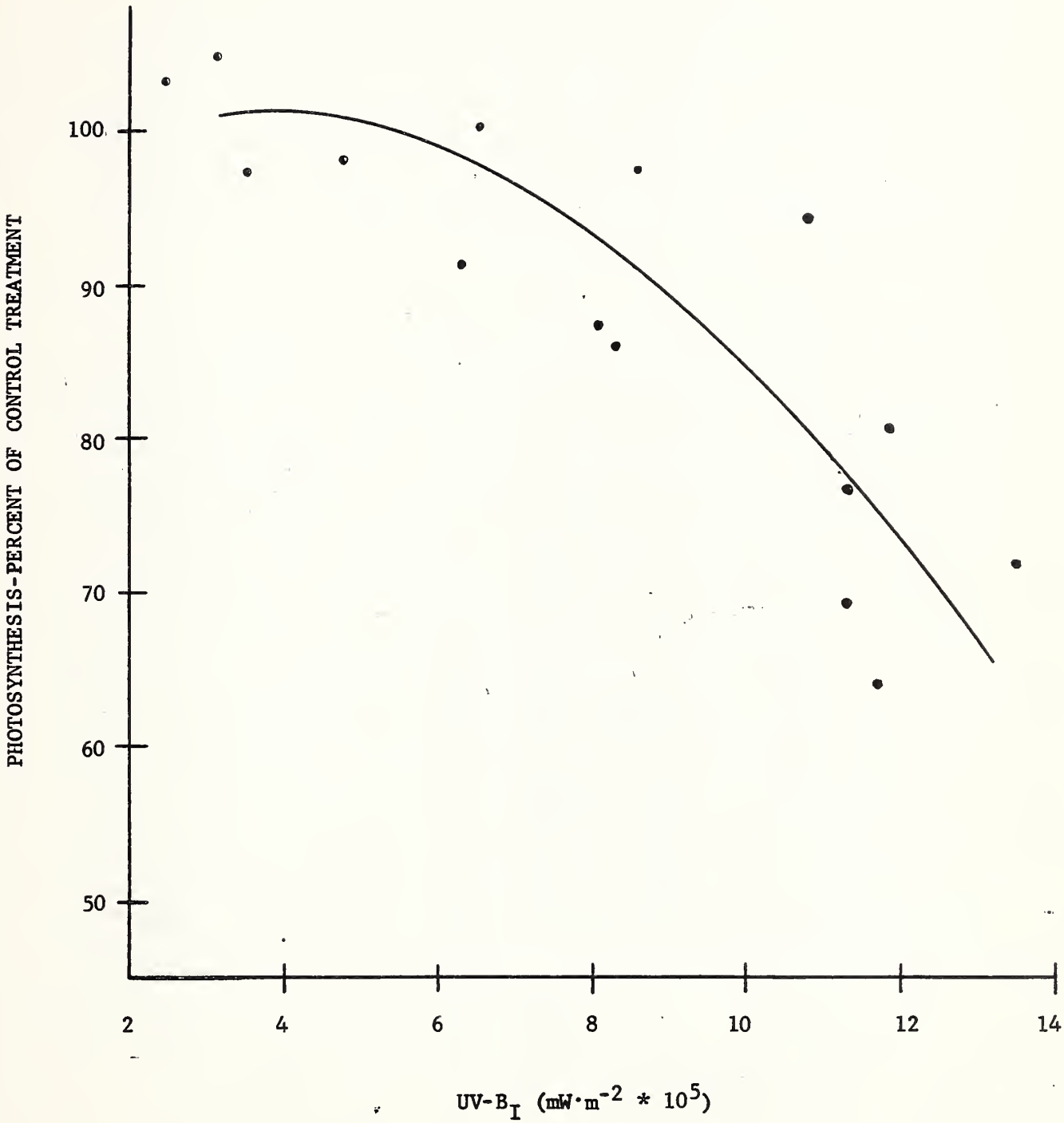

1.0
.75
.50
.25
0
ABSORBANCE
250
275
300
325
350
375
400
WAVELENGTH (nm)

Figure 13. Net photosynthesis of Cucurbita pepo f.s. early summer crookneck exposed to four UV-B radiation treatments (5.1, 6.8, 7.7 and 9.1 mW . m^{-2} $UV\text{-}B_I$) expressed as a percent of the control treatment plant rates.


PHOTOSYNTHESIS-PERCENT OF CONTROL TREATMENT
100
90
80
70
60
50
2
4
6
8
10
12
14
UV-B$_I$ (mW·m^{-2} * 10^5)

it had fully expanded.

Net photosynthetic rates of UV-B radiation treated plants appeared to be repressed after exposure to approximately $6 * 10^5$ mW . m^{-2} $UV\text{-}B_I$ and continued to be reduced upon additional UV-B radiation exposure. This same type of accumulative response in the depression of photosynthesis has been shown earlier by Sisson and Caldwell (1976) for Rumex patientia L.

Summary

The findings of this study are consistent with earlier biological studies involving an enhanced terrestrial UV-B radiation component of the global irradiance spectrum. That is, photosynthesis is depressed in an accumulative manner and plant growth tends to be depressed as a function of the level of UV-B radiation to which plants are exposed. However, it is interesting to note that plants apparently possess an ability to respond to UV-B radiation by synthesizing UV-B radiation screening compounds such as the flavonoids. To what extent this response would have in negating the UV-B radiation induced damage cannot be determined at the present time. Results of this study utilizing low levels of UV-B radiation, as well as previous findings (Sission and Caldwell, 1977), would tend to suggest that an intensified synthesis of UV radiation screening compounds does not afford sufficient protection to sensitive target molecules within plant cells of the more sensitive plants.

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